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NATIONAL MISSILE DEFENSE (NMD) INTEGRATED GROUND TEST (IGT) VALUE

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Abstract

Test and Evaluation (T&E) of the National Missile Defense (NMD) system is an expensive and complex undertaking. A challenge facing the NMD T&E community is allocation of scarce test resources to achieve necessary system testing within available funding. This allocation is done on the basis of perceived value across a number of test methodologies of which Integrated Ground Tests (IGTs) are one. This paper is based on identified value and lessons learned during recent NMD integrated ground testing. The primary objective of this paper is to identify and explore the value of IGTs by showing how they meet NMD T&E challenges. These challenges are associated with cost, fidelity and completeness of system representation, and utility. The IGT detailed design and implementation process is discussed in relation to interactions with the NMD T&E community and the integrated system test tool developer. A description of the process is provided. Recent lessons learned are presented with insight into how to apply them to increase the value of future IGTs. Unique IGT value is identified. It is also shown that IGT value is synergistic with the value of other test methods and processes.

Introduction

This paper is organized in three parts. Part I presents an overview of the challenge involved in ground testing of an NMD system and defines both a generic IGT process and the value expected to be derived from this process. Part II describes the IGT detailed design and implementation process, identifies more detailed and recently identified IGT value, and introduces flexible variations of the process. Part III explores recent IGT lessons learned with focus on increasing the value of future ground testing.

I. Overview

Known Challenges

It has been observed that test is the conscience of the development and acquisition process. The fundamental purpose of test and evaluation in this process is to identify risk areas to be reduced or eliminated.[1] A recent independent DoD study concluded that Ballistic Missile Defense (BMD) programs need to pay more attention to ground testing, simulation, and analyses so as to reduce issues to be resolved in flight tests to those that can't be resolved with ground testing or simulations.[2] It also recommended a formal process to ensure full certification of the system before each flight test. Of course, not all data required for making a system deployment decision is available from flight tests. A considerable body of additional data is required to support the Deployment Readiness Review (DRR) in the year 2000. This data would come from a number of sources including IGT and Model and Simulation. So the challenge for NMD T&E is to optimize the value of testing done with each available test methodology. This optimization must be done with consideration of real world constraints that limit the value derived from each methodology.

Consider the major available system test methodologies for the NMD system. These are Integrated Flight Test (IFT), Integrated Ground Test,

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and Model and Simulation (M&S). An IFT involves test of an actual representation of the NMD system in a real-world environment. As a minimum, Intercontinental Ballistic Missile (ICBM) target and NMD interceptor launch(es) at National Ranges are involved. These are very complex and costly at tens of millions of dollars per test. Only a few of these can be afforded. IFTs are not suitable for statistical data collection due to test sample size. However, they have the most credibility since they come closest to placing a real world NMD system in a real world warfighting environment. They are destructive tests that produce only limited amounts of high quality test data. Risk reduction for IFTs is thus imperative. Major IFT features are shown in Figure 1.

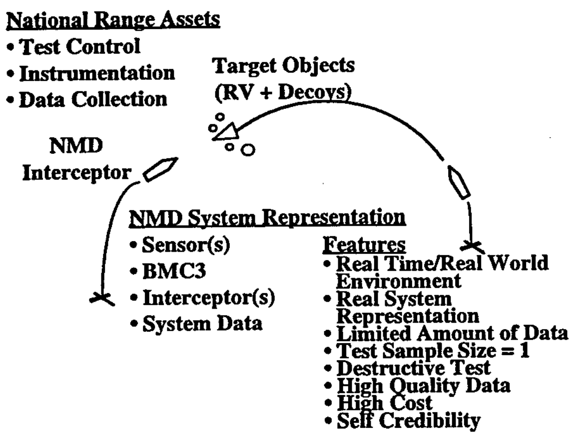

Figure 1. Major IFT Features

An IGT is a non-destructive test involving two or more NMD system element hardware/software test articles operating in a system context in a common test environment. These element test articles consist of actual operational software operating in actual data processing hardware of the element. An example would be an interceptor data processor running the same software it would in an actual interceptor. This test article is realized as an element node that is interfaced by tactical NMD communications to the other participating element test articles. This element node is sometimes referred to as a Processor Test Environment (PTE) that is interfaced to a Node Test Environment (NTE) of the system test tool. The common test environment at the NTE provides simulated detailed threat object dynamics, natural environments (rain, clouds), backgrounds (sun, moon, stars, earth, satellites), and nuclear effects. Only a minimal amount of NTE/PTE element interfacing simulation is needed to complete the system representation. The result is a real time test configuration of real world interfaced system hardware/software and minimal interfacing simulation that responds as a system to a simulated test environment. Validation is thus only required for the non-real world simulated test environment and the interfacing simulations. IGT is the test methodology next highest in actual system realism to an IFT. IGT is also suitable for limited statistical data collection due to the capability to perform a moderate number of repetitive runs. Major IGT features are shown in Figure 2.

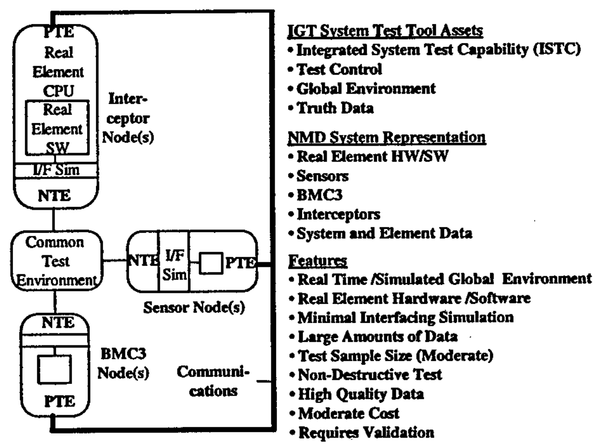

Figure 2. Major IGT Features

M&S substitutes computer representations for the actual hardware of the integrated system elements. This methodology requires significant accreditation activity before it is trusted since all system component model representations need to be accredited in addition to the simulated environment. M&S can be run faster or slower than real time depending on model complexity and executing digital computer capability. The faster than real time feature makes M&S suitable for many repetitive runs and collection of statistical measures of performance. M&S features are shown in Figure 3.

IGT Process

The IGT process can be viewed as a closed loop feedback process that takes input from the NMD T&E community and the system elements and produces analyzed data and lessons learned as outputs. Figure 4 shows the major components of this process as 1) system test tool development with associated system element integration, 2) detailed test design, 3) test implementation, and 4) data analysis.

Computer Simulation Assets

- **General Purpose**
  - **NMD System Representation**
    - **Simulated Sensors**
    - **Simulated BMC3**
    - **Simulated Interceptor(s)**
    - **M&S Data**

Features

- **Variable Time/Simulated Environment**
- **Large Amounts of Data**
- **Test Sample Size (Large)**
- **Non-Destructive Test**
- **Data Quality Dependent on Validation**
- **Low Cost**
- **Requires Significant Accreditation**

Figure 3. Major M&S Features

The system test tool is developed in incremental builds for each specific test. This development is intimately associated with integration of the evolving NMD element hardware/software at their current states of maturity. NMD elements are interfaced together as a functioning system representation that responds to the simulated real time test environment. The system test tool providing the common test environment is the Integrated System Test Capability (ISTC) under development in Huntsville, Alabama. ISTC was the system test tool used in the recent IGT 1A test. The system test article representation includes the necessary integrated sensors and the Battle Management/ Command Control and Communications (BMC3) as well as the interceptor(s). The integrated system test tool and system test articles combined comprise the test configuration. Each build of the test configuration must pass incremental integration testing along with any required accreditation or other testing. Upon completion of the build, a usable system test configuration exists for test implementation at which point test assets are declared available. This Test Assets Available (TAA) milestone is time phased to occur just before the Test Design Review (TDR) so that the baseline system test configuration can be presented for major review at the same time as the final detailed test design.

Detailed test design is an interactive process driven by inputs from the NMD systems engineering community but also balanced by knowledge of the

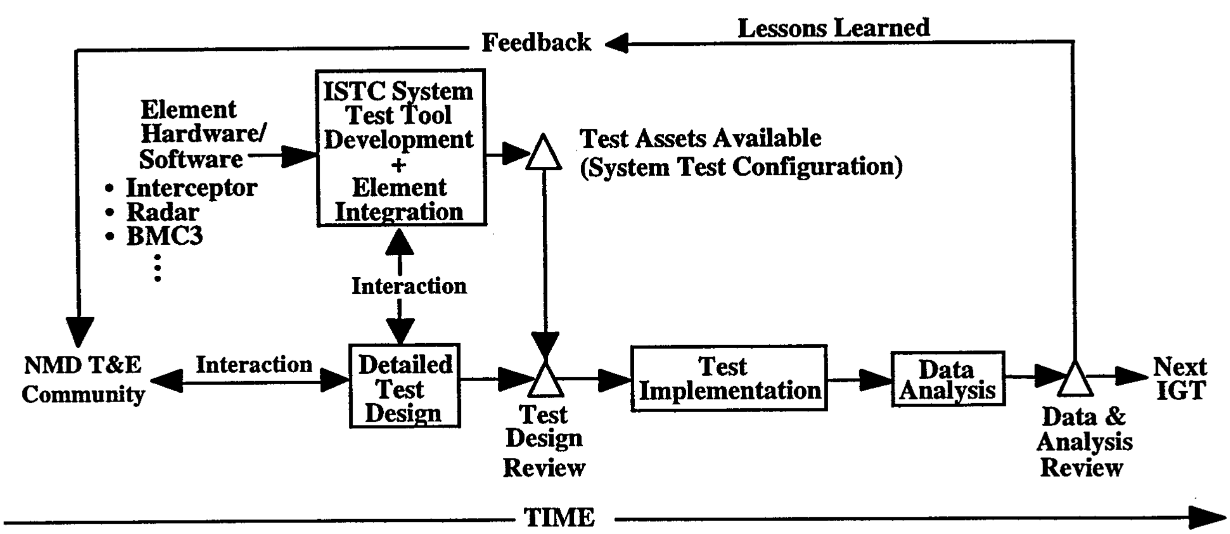

Figure 4. Integrated Ground Test Process

evolving capability of the system test tool and the embedded system test article representation. This process takes test objectives, test requirements, and data requirements from the NMD T&E community and uses them to develop a coordinated single detailed plan for test implementation that is consistent with the current maturity level of the system test configuration. This design is currently captured for use by the test implementation team in three design documents. These documents are the Detailed Test Plan (DTP), the Interface Definition Document (IDD), and the Data Management Plan (DMP). Before this design is implemented it must pass a major review by the test community at the TDR.

Test implementation is a structured process that prepares both the test operations team and the test configuration for formal runs-for-record testing under configuration managed conditions. Test data is then generated during runs-for-record in accordance with the detailed design for designated data customers that will use that data in the subsequent data analysis activity. A Quick Look report is prepared soon after conclusion of runs-for-record to provide preliminary test execution information. Test data is then reduced and delivered to the data customers as specified in the detailed test design. In order to put the test data in best usable context, a Post Test Execution Report (PTER) is prepared that describes the implementation of the IGT along with the processes that were used to assess the data and the test configuration management (CM). The PTER also provides tabular and summary documentation of any hardware and/or software anomalies encountered during runs-for-record. This context information is useful to the data analysts for their analyses.

Data analysis by IGT data customers is independent of both the test implementation team and the system test tool developer. A Post Test Analysis Report (PTAR) is prepared to document the assessment of results of an IGT as related to the test objectives. Data customers are invited to present their interim or final analyses at a Data and Analysis Review as the last activity in the IGT process. Results of these analyses are then available as feedback to the NMD community to aid preparations for the next IGT.

Value Expected

While IFT can provide but a limited quantity of highly credible data, M&S can provide large amounts of usable data if M&S can be made creditable. This places high value on a workable methodology to transfer IFT credibility to M&S. IGT can provide this through the process of anchoring. Anchoring uses an IGT to reproduce the high quality IFT data result for a given scenario or point of interest. Resolution of differences in this comparison requires improvements in only the simulated part of an IGT, which is minimal. The rest of the IGT uses the same hardware and software as the IFT and uses accredited test community simulations of the test environment. Point validation is considered easier for IGT than M&S for this reason. This reproduction of results provides a point validation of the IGT against the current system performance envelope. Additional IFT can provide additional point validations at different points on the performance envelope and can give the IGT high credibility. Transfer of this credibility to M&S utilizes data available from IGT at these validation points as well as points not testable in IFT: multiple interceptors engaging multiple threat objects in various tactical geometries. M&S then has the necessary amounts of high quality data needed to perform validation of all the M&S components. M&S can produce large amounts of credible decision data to include statistical data to be used in the DRR.

An IGT is also part of building a test capability that increases in value for each subsequent IGT. Value is increased by providing confidence in the reduction of program risk. This confidence is provided by demonstrating increasing capability in the T&E of the system as system performance increases over time. Aspects of this capability are visible as 1) ability to perform system assessments against system requirements, 2) ability to document complex system tests, 3) ability to train personnel to integrate a system test configuration, conduct a test and reduce data products, 4) ability to perform NMD system integration with all necessary sub-components and deal effectively with accreditation requirements, and 5) establishing test infrastructure useful for long-term IGT.

A subtle but very important IGT value is associated with the first forced integration of elements that previously have not been required to operate together in system context. An IGT with first time element participation will invariably reveal interactive issues not previously anticipated. Early identification facilitates resolution.

Another value expected is the establishment of a common level or standard of test configuration management discipline. Each organizational participant enters the IGT process with differing CM standards. The detailed test design brings these standards together at the test-tool-to-element and element-to-element interfaces. This same discipline is used to maintain an audit trail for collected test data credibility.

Of considerable importance is the value of forging a common set of test expectations from the test participants who come from different test backgrounds with their own separate semantics and practices. This lack of common test expectations is most evident during the detailed test planning coordination when the proponents of the top-down requirements approach clash with those favoring the bottom-up capability approach. Both approaches have merit. The system must eventually be tested against NMD system requirements but early IGT testing must use available system element components that are still maturing but currently only meet pre-existing long lead contract requirements. Typically the system engineer would take the former approach and the elements would take the latter approach. Both approaches must be balanced in planning an IGT. Whether agreement is reached on all objectives or not, a common understanding emerges on what is doable in a given IGT.

II. Detailed Design and Implementation

Detailed Design

Detailed test design begins with initial test and data requirements analysis and early research into achievable test configuration design. A Technical Interchange Meeting (TIM) is used to kick-off formal detailed test design. Participants meet, exchange information and begin the necessary coordination. This design is captured in detailed design documentation (DTP, IDD, DMP) that is developed and reviewed incrementally. The NMD test community influences this design through information input, coordination, and participation in major reviews. The goal is to converge the detailed design, to define the test interfaces and messages, and to define the data management process for identifying, handling, and distributing specific IGT data products. The purpose of the DTP is to provide details for the Test Director to implement/execute a specific IGT. These details include 1) test objectives, 2) test requirements (allocation to test configuration), 3) data requirements (what, how, who are data customers), 4) scenarios, 5) implementation activities (pre-test, test, post-test), 6) test configuration description, and 7) test management and controls (roles and responsibilities, configuration management, security and safety, schedule and change process). The purpose of the IDD is to define test interfaces and messages for use by the Test Director to document test interfaces for interface data capability and test CM. The purpose of the DMP is to define the data management process for identifying, handling, and distributing IGT data products. It is used by the Test Director to document the data management process and to control the distribution of data products. Each design increment is an opportunity to resolve design conflicts and update the detailed design. Design documentation is then finalized and presented for review at the TDR.

Implementation

Test implementation begins as soon as possible after an authority to proceed (ATP) is granted at the TDR. This ATP is generally granted at the TDR upon evidence that the test configuration and the detailed test design are acceptable and both have been placed under test configuration management. Test configuration baseline is established at the Test Configuration Control Board (TCCB) concurrent with the TDR. Major activities in test implementation are 1) test preparation, 2) runs-for-record, and 3) data reduction/reporting.

Test Preparation

The test preparation starts with turnover of the available test assets baseline from the system test tool developer to the test implementation team under CM controlled conditions. This involves replacement of all system test tool developer computer/network access privileges with test CM and test implementation team access privileges. All changes to the baseline test assets and detailed test design that are found necessary for test success during this preparation phase are made and documented for a test CM audit trail. Several activities occur in parallel during preparation to save test time. Finalization of the test procedures is done by the implementing operations team while they are performing interface verification testing to verify the baseline test configuration as advertised in the baseline test CM documentation. Concurrently, test setup files for each scenario to be run are generated and stored for use during runs-for-record. Also concurrently, post-run scripts are developed for use in data reduction to meet the specific data requirements for each data user identified in the detailed test design. When all setups, scripts and procedures are finalized and verified, then the implementing operations team performs dry runs in the same manner as planned for runs-for-record. This involves use of the configuration controlled procedures and the test configuration by the actual operations crew to collect readiness evidence for presentation at a Test Readiness Review (TRR). Authority to proceed into the formal runs-for-record is granted at TRR upon evidence that test risk is acceptable.

Runs-for-Record

Runs-for-record are formal IGT runs witnessed by test observers from the NMD T&E community and Other Government Agencies (OGAs). They are executed under the direction of a responsible Test Director with direct control of a Test Conductor who manages and coordinates the day-to-day conduct of the formal runs. The test operations team operates the common test environment (test and control, global environment) as well as any necessary NTE equipment. Each element node has a designated PTE operator(s). Facility support personnel and a system test tool technical expert are on-call as needed by the Test Conductor. All operational participants are tasked by the Test Conductor to execute the runs.

Data Reduction / Reporting

After each test run, raw captured data is transferred from the several collection points to a single workstation for test CM identification and control. Between real time test runs, the data is available for spot check by the test operators for null, incomplete, or corrupt data sets due to vagaries of the test such as electrical storm induced errors. Spot checks only are available since the data is not yet in human readable form and the amount of data is very large. However, if a spot check reveals a problem at this point, the Test Conductor has the option to repeat the test run. This option provides a method for confirming that requested data for designated data customers has actually been collected before releasing the system test tool. During post-test data reduction, a post processor converts the data to ASCII format and separates it into files according to data requests documented in the DMP. The resulting processed data files are also brought under test CM. At this point both raw and processed data files are available for transfer to removable media for delivery to DMP-specified data customers.

Daily reporting by the Test Conductor to the Test Director is provided for management visibility and to provide an opportunity to identify any daily run problems requiring attention before start of the next day's runs. A Quick Look Report is prepared within 48 hours of runs-for-record completion. This report is coordinated with all on-site operator participants and identifies whether all data necessary to meet test objectives was collected as specified in the DTP. It also contains preliminary assessments of the completed test runs. A PTER is prepared not only to document the test execution but to aid data customers in appropriate use of data. This report describes the test as performed, provides a test execution and data collection assessment, reports anomalies, identifies corrective actions required, provides lessons learned, and gives recommendations for future IGT. Inputs, reports, and conclusions are solicited from on-site test participants for inclusion.

Recently Identified Value

Important value is placed on the ability to shorten the data reduction/analysis/lessons learned timeline. This ability will provide timely information to allow influence of the design of the following IGTs in a very compressed and over-lapping test schedule. Achieving this ability remains an IGT challenge due to issues associated with the amount of generated data, the need for credible test CM, the speed of data media copying equipment, and security requirements. The magnitude of just the data amount issue is growing with each capability improvement made to the system test tool as shown in Figure 5. This figure provides data collection totals for the recent IGT 1A conducted in April and May of this year and compares them with totals observed for the Integrated Test 3 (IT3) which was an informal IGT-like ground test conducted in the summer of 1997. IT3 involved additional runs for equal treatment of competing Exo-atmospheric Kill Vehicle (EKV) contractor test articles that participated.

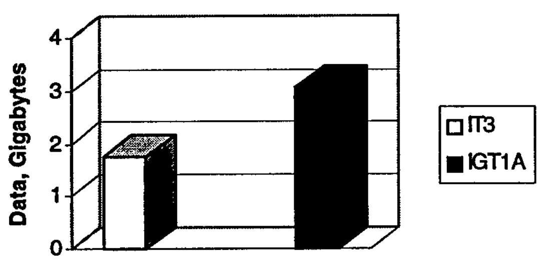

Figure 5. Demonstrated Data Collection

Element organizations place a high value on the control and management of data and information about their element performance. This reflects a legitimate point of view for element organizations but it remains an issue that needs to be balanced against the needs of the NMD system. Resolution of this issue is expected as elements are brought under the management of the NMD Lead System Integrator (LSI).

The ability to maximize the number of runs achievable per work shift is valuable in scheduling scarce dedicated system test tool and facility time. It must be noted that IGT implementation schedules compete with time needed for developing the next IGT test configuration. Much work overlaps due to compressed scheduling. The solution is to minimize test run cycle time. Run cycle time is the sum total of the contiguous clock time required to setup a specific run, to execute that real time run and to move collected run data to a safe CM location while initializing for the next cycle. Observed average cycle times are shown in Figure 6 for the previously mentioned IT3 and IGT 1A tests. Note that IGT 1A cycle time was longer than that for IT3. This is attributed to the addition of a complex node to the test configuration. Recycle time is expected to grow as further additional nodes are added to the test configurations for future IGT. Also note that average cycle times for both IT3 and IGT 1A were decreased during runs-for-record compared to the preceding averages observed during the test preparation phase of test implementation. This valuable decrease is attributed to test operator practice with a stable configuration managed test configuration and test procedures.

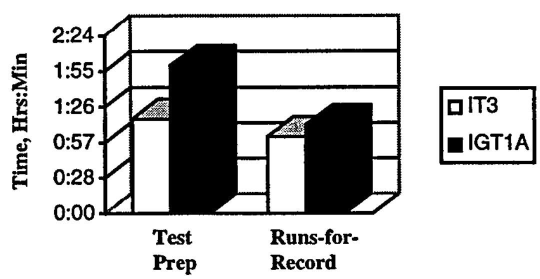

Figure 6. Demonstrated Cycle Time

Variations

There are several possible variations of the IGT process. These differ from IGT in degree of formality, visibility to the test community, degree of tested functionality, purpose, level of configuration management, OGA participation, and availability of generated data. Examples of these are System Development Test (SDT), Integrated Element Test (IET), Integrated Test (IT), System Interface Test (SIT), Readiness Test Assessment (RTA), IFT Pre-mission Test (PMT) and Element Test (ET). Additional variations are possible.

An SDT might focus only on whether the system test tool functionality meets development requirements with an embedded system. An IET, IT, or SIT might have IGT-like test configurations but be conducted informally with narrow objectives, reduced test CM, and limited availability of the data products. An RTA might be conducted informally with reduced test CM and a preliminary IGT test configuration for purpose of maintaining and increasing IGT operator skills. A PMT would be conducted to reduce risk for a subsequent IFT with similar NMD system representation. Finally, an ET might be conducted for a specific element in a system context but involve both limited visibility and limited data availability under element control.

III. Lessons Learned

Lessons learned to date from the recent IGT 1A can be grouped into categories associated with 1) test design, 2) procedures and 3) hardware and software.

Test Design

Early element and system engineer involvement is needed to define test objectives, test requirements, and the test configuration. It was observed that there is a tendency of the T&E test community to delay identification of issues critical to the final detailed design. It was also observed that key issues surfaced fastest when system engineer and element representatives participated in face-to-face coordination as part of the detailed design. It will be valuable to future IGT for small design working group sessions to be used early in the detailed design as the forums for the necessary system engineer and element involvement.

The level of element test configuration management needs to be more uniform across all elements with standards established as part of the detailed design. Ability to accurately document the test configuration and interfaces will be significantly improved by this measure.

Data customers need to provide more complete addresses in the DMP of Points of Contact (POC) and alternates that are authorized to receive the data. Large amounts of classified data are involved and needed for timely analysis. This measure will avoid delays in data delivery and subsequent start of analysis. It will also provide a means for dealing with absent POCs and POCs that change subsequent to the DMP finalization.

There is a need for an improved method to obtain test community input and coordination for the detailed design documentation. IGT can borrow the effective technique used by IFT of a page-by-page and sit-down review of detailed design documentation.

Early identification of collected data formats is necessary to aid data analysis planning. Advance knowledge in this area will allow data customers to prepare and test advance analysis templates that will speed data analysis upon data delivery. This measure will involve more accurate early data format identification by both the elements and the system test tool developer for inclusion in the IDD.

Element data collection capability needs to be identified in the detailed design documentation and implemented in the test configuration prior to the TAA milestone. This measure will allow data customers to know in advance of test implementation what element data will be available to support their analyses.

The accreditation process for elements in the test configuration needs clarification in areas of required tests, data, schedule, primary POCs, and any other activities required. Element representatives were unaware of precise requirements for each accreditation phase in IGT 1A.

Early development of accreditation acceptability criteria is needed with clear decision authority identified. It will be valuable to the next IGT to develop acceptability criteria early with inputs from representatives of elements and Operational Test Agencies (OTAs).

Procedures

Training exercises are required to train operators and verify procedures before TRR. This measure is critical to IGT effectiveness in a compressed schedule.

Test operations team capability needs to be maintained by conducting RTAs on a regular basis. Operations team must be skilled on latest modifications to system test tool and element functionality.

It is important to formally document all IGT problems encountered and track them until resolved. Otherwise, it is probable that the same problem will be encountered on a future IGT.

An independent procedure is needed to verify the proper test configuration file has been established without configuration setup error. This lesson was learned and implemented in IGT 1A.

Element personnel need direct access to test data and reports from each system test tool/element integration phase. Data and reports were not available until all integration test phases were complete during IGT 1A system test tool development and element test article integration.

A radar node procedure modification is needed to ensure the proper NTE clock time is used by the radar element node operator. This lesson was learned and implemented in IGT 1A.

A radar node procedure modification is needed to ensure both PTE processor machines are operating at proper clock frequency before starting test. This lesson was also learned and implemented during IGT 1A.

Hardware and Software

Software script for fetch of BMC3 post-run element data needs error handling or flagging to reduce potential for operator error.

System test tool timeline software needs modification to allow playback of collected data after CM data lock-down.

The system test tool needs modification to provide faster data archiving of large amounts of collected data. The current tape archiving system is unacceptably slow.

A system test tool software modification and improved software documentation are needed to reduce risk of improper setting of data collection latches during pre-mission test configuration file setup.

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